results indicate that a low barrier height MSM diode, such as a Ni—InGaAs—Ni diode or the p-type Ir—Si—Ir diode, can potentially be used to efficiently rectify optical frequency radiation at zero bias for solar to electric energy conversion. Additionally, FIG. **6** includes an inset graph **650** that includes axis **652**, axis **654**, and curve **656**. Axis **652** is the current density in amperes per cm^2. Axis **654** is the bias voltage in volts. Curve **656** depicts a linear J-V curve of the p-type Co—Si—Pt diode.

[0040] FIGS. **7***a-c* show examples of energy band diagrams **700**, **710**, and **720** corresponding to the different J-V curves **610**, **612**, and **614** of the different MSM diodes of FIG. **6**. FIG. **7***d* shows an example of an energy band diagram **730** corresponding to the theoretical semi-log J-V curve **616** of the Schottky diode of FIG. **6**. In the energy band diagrams **700**, **710**, **720**, and **730**, h^+ and e^- represent the charge carriers emitted into the semiconductor layer in a direction shown by the arrows **702**, **712**, **722**, and **732**.

[0041] The Si layer **714** for the p-type Co—Si—Pt diode and the Si layer **724** for the n-type Cr—Si—Cr diode may be doped with a concentration of dopants that is 5×10^{15} cm^{-3} or less. For the p-type Co—Si—Pt diode, a thickness of the Si layer **714** may be approximately 30 nm, and a surface in contact with the Pt layer **716** may be degenerately doped with boron with an estimated surface concentration of approximately 1×10^{20} cm^{-3}. For the n-type Cr—Si—Cr device, a thickness of the Si layer **724** may be approximately 60 nm, and one side of the Si layer **724** may be degenerately doped with phosphorous with an estimated surface concentration of approximately 2×10^{20} cm^{-3}. Contact resistances R_C, i.e., carrier tunneling impedances from metal into Si, were calculated to be approximately 5×10^{-9} Ωcm^2 and 2×10^{-8} Ωcm^2 for Pt—Si and Cr—Si interfaces, respectively.

[0042] A size of a MSM diode is defined by an overlap in a section of a semiconductor layer between top and bottom metal contacts of the diode. J-V curves for both p-type and n-type MSM diodes exhibit an exponential rise as a function of forward bias, given by the following equation:

$$J(V)=J_0[\exp(qV/\eta k_B T)-1], \tag{1}$$

where J_0 is the saturation current density, T is the temperature, q is the electron charge, V is the bias across the diode, k_B is the Boltzmann constant, and η is the ideality factor which is 1.25 for both p-type and n-type devices. Generally, the thicknesses of the silicon layers of the devices result in current-voltage (I-V) characteristics that follow thermionic emission mechanism. Tunneling contribution is expected to be small, especially at low biases. The corresponding J_0 for the Co—Si—Pt and Cr—Si—Cr diodes are 8.5×10^1 A/cm^2 and 1.3×10^{-1} A/cm^2, respectively. These values are significantly higher than values of J_0 for Co—Si and Cr—Si Schottky diodes.

[0043] While a MSM diode described in the present disclosure may have some features similar to a typical Schottky diode, a MSM diode includes features that are different than a typical Schottky diode. For example, in a MSM diode, carriers are launched directly from a metal emitter where an electron density is very high, and carriers travel across the semiconductor ballistically. Additionally, with both metal emitter and collector, a series resistance R_S in a MSM diode can be lower than 10^{-11} Ωcm^2, which may be virtually negligible, leading to a cut-off frequency higher than 100 THz.

[0044] Due to a high current density, a true cut-off frequency limit of a MSM diode was not fully characterized before an electrical contact away from a diode junction was "burned". Based on the J-V curves shown in FIG. **6**, which show that currents of the MSM diodes do not exhibit noticeable deviation from the exponential rising curves, the upper limit of the series resistances can be estimated to be 5×10^{-9} Ωcm^2 and 3×10^{-8} Ωcm^2 for the Co—Si—Pt and the Cr—Si—Cr diodes respectively, according to a noise level in the measurement.

[0045] Since the silicon layer is completely depleted, a capacitance of a MSM diode can be evaluated by the following equation:

$$C=\epsilon A/d, \tag{2}$$

where ϵ is a dielectric constant, A is a device size, and d is a thickness of a silicon layer. Corresponding capacitances for the Co—Si—Pt and the Cr—Si—Cr devices when normalized to 1 cm^2 are 3.5×10^{-7} F and 1.8×10^{-7} F, respectively. The cut-off frequencies can be evaluated by the following equation:

$$F=1/(2\pi R_s C), \tag{3}$$

and are estimated to be 1×10^{14} Hz and 3.7×10^{13} Hz for the Co—Si—Pt and Cr—Si—Cr diodes, respectively.

[0046] Table 1 below summarizes saturation current densities J_0 for different diode devices. The observed saturation current density of a MSM diode is substantially higher than that of a conventional Schottky diode with identical current limiting metal-semiconductor junctions, for both p-type and n-type MSM devices. The observed J_0 for both p-type and n-type diodes are between 100-1000 times higher than values calculated using a typical thermionic emission mechanism that assumes only certain carriers can contribute to the electric current. These carriers have vertical (to the junction interface) components of their velocities $v_\perp$ that can provide enough kinetic energy to overcome the barriers.

TABLE 1

Saturation current densities of Schottky and MSM diodes.

	Emission limiting barrier height (eV)	J_0 - Schottky diode (A/cm^2)	J_0 - MSM diode (A/cm^2)
Co—Si(p)	0.45	9×10^{-2}	8.5×10^{1}
Cr—Si(n)	0.6	1×10^{-3}	1.3×10^{-1}
Cr—Si(p)	0.57	1.3×10^{-3}	3×10^{-1}

T = 300 K and Richardson constant = 120 A/(cm^2K^2) were used for the calculation.

[0047] A number of implementations have been described. Nevertheless, various modifications can be made without departing from the spirit and scope of the processes and techniques described herein. In addition, the processes depicted in the figures do not require the particular order shown, or sequential order, to achieve desirable results. In addition, other steps can be provided, or steps can be eliminated, from the described processes, and other components can be added to, or removed from, the describe apparatus and systems. Accordingly, other embodiments are within the scope of the following claims.

What is claimed is:

1. A diode, comprising:

a semiconductor layer having a first side and a second side opposite the first side, the semiconductor layer having a thickness between the first side and the second side, the thickness of the semiconductor layer being based on a mean free path of a charge carrier emitted into the semiconductor layer;